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The AEROVOX Research Worker



The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 22, NO. 3

MARCH, 1952

Subscription By Application Only

Proper Use of By-Pass Condensers

By the Engineering Department, Aerovox Corporation

IN modern electronic circuits the capacitor is used more frequently for the function known as "by-passing" than for any other single application. The selection of a capacitor of the proper type and value for a given job is an important aspect of circuit design. Such critical performance characteristics as frequency response, phase distortion, circuit stability, and freedom from parasitic oscillations are determined by the by-passing used. This discussion is intended to provide a review of this subject for the benefit of the amateur, experimenter, young engineer, or anyone who has been puzzled by the problem of what by-pass to use for a specific purpose. The factors underlying the choice of capacitors in typical circuits will be pointed up by the use of examples.

"By-passing" can be defined as providing a short, low impedance path around certain circuit components for electrical currents of some frequencies, while maintaining a high impedance path for other frequencies. The circuit designer is repeatedly confronted with the need of components having this property of passing currents of a desired periodicity while excluding others. Actually, both inductances and capacitors qualify under this definition because of the frequency discriminating action of these simple filters. An inductance, or "choke", may be considered to be a

low frequency by-pass element since it presents a low impedance path for d.c. and low frequencies while presenting a high reactive impedance for high frequencies. The condenser, on the hand, is a simple high-pass filter, having a high reactance at low frequencies and becoming more nearly a short circuit as frequency is increased. It is when this latter property is used to provide a "detour" around some part of a circuit that the term *by-passing* is most commonly employed.

For a capacitor to function as an effective by-pass, its impedance must be much lower than the impedance of the circuit element being by-passed. Of course, the reactive impedance of a capacitor of any value is easily calculated for any given frequency from the basic expression:

$$(1) \quad X_C = \frac{1}{2\pi f C}$$

Where:

X_C is the capacitive reactance in ohms

f is the frequency in cycles per second

C is the capacitance in farads

Provided that $X_C \gg X_L$, X_L = lead reactance.

Needless to say, this relationship is of constant use in designing proper by-pass circuits. It shows that the reactance of a given unit decreases with frequency or that, for a given

frequency, a value of capacity can be chosen to give any desired value of capacitive reactance. To aid in visualizing this function, we have plotted the reactance of a .001 mfd. condenser versus frequency in Fig. 1.

Cathode Resistor By-Passing

The most frequent use of the by-pass condenser is illustrated in Fig. 2, where the capacitor is used as a *cathode resistor by-pass*. The necessity for this is obvious when the characteristics of the circuit are considered. As is well known, any vacuum tube stage which uses cathode bias exhibits strong degeneration if the signal current is allowed to flow through the bias resistor. This is so, as the a.c. component of the plate current flowing through the bias resistor develops a voltage drop across it during signal peaks which increases the bias applied to the grid of the tube. This has the effect of reducing the signal voltage on the tube grid and thus reducing the stage gain and introducing phase distortion and other undesirable results.

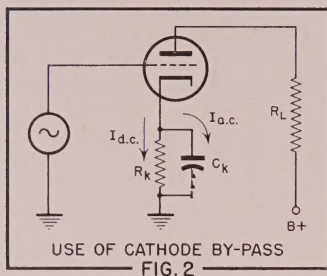
In Fig. 2, this degenerative effect is prevented by shunting the cathode bias resistor with a capacitor which by-passes the a.c. signal component around it. Let us now consider the requirements placed upon this capacitor.

Assume that the stage depicted in Fig. 2 is an audio amplifier intended

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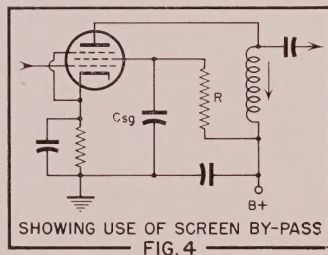


to work over the frequency range of 200 to 5000 c.p.s. and that the cathode resistor recommended for the tube type used is 300 ohms. A bypass capacitor must be provided across this resistance which will prevent most of the audio frequency plate signal current from flowing through it. Since the reactive impedance of the condenser becomes lower with increasing frequency, as shown by Eq. 1, one which is satisfactory at the low frequency end of the desired range will do for the entire range. Therefore, in the present example, a capacitor which effectively bypasses the 300 ohm cathode resistor at 200 c.p.s. should be adequate. Most circuit designers consider a ratio of bias resistance to by-pass reactance of about 10-to-1 to be a safe rule-of-thumb for most work. With this ratio more than 99% of the total a.c. current flows through the by-pass condenser. Ratios up to 20-to-1 may be used in high fidelity amplifier work where space and economical considerations permit, however.

Assuming a by-pass ratio of 10-to-1 to be sufficient, a capacitor having a reactance of one-tenth the resistance of the bias resistor at 200 c.p.s. is necessary. By rewriting Eq. 1 to solve for a value of capacitance having a reactance of 30 ohms, an answer of 26 microfarads is obtained. Therefore, the nearest standard value of 25 microfarads would be used. An electrolytic condenser is usually used in this application since leakage resis-

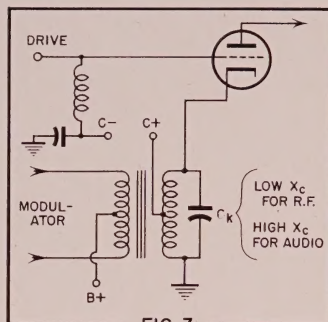
tance is not important in this case and these units are compact and economical. The capacitor must be rated for a working voltage greater than the maximum bias voltage developed. This may be obtained from Ohm's Law, using the bias resistance and the maximum d.c. current which flows through it. For pentodes, this means both the plate and screen current, and for classes of amplification other than Class A requires the maximum-signal current. A voltage rating of 25 or 50 volts is usually sufficient for cathode by-passing.

In the example discussed above, the cathode by-pass could have been made large without limit, without detrimental effects on circuit performance. Circuits exist, however, in which there is an upper limit to the capacitance which can be used to bypass an impedance in the cathode circuit. As an example, consider the cathode-modulated Class C r.f. amplifier shown in Fig. 3. Here the condenser is required to by-pass r.f. around the modulated transformer. Otherwise regeneration may result from feedback into the grid bias circuit. However, if the cathode by-pass



is made too large, the modulation frequencies will be shunted to ground. A value of capacitance must be chosen which has very low reactance at the carrier frequency, but a high one at the highest modulation frequency. Fortunately, this is easily done in this case because of the wide difference in the frequencies involved; a .002 microfarad condenser has a reactance of about 8.0 ohms at an r.f. frequency of 10 Mc. but almost 16,000 ohms impedance at 5000 c.p.s. A good mica or ceramic condenser of low inductance would be used in this application.

Of course, not all cathode bias resistors must be by-passed. In many high fidelity audio amplifiers and television i.f. amplifiers controlled amounts of negative feedback are introduced to improve the over-all performance. In such cases, the loss of gain is compensated by adding extra stages. Cathode by-passing is also omitted in Class A push-pull amplifiers, since the a.c. signal compon-

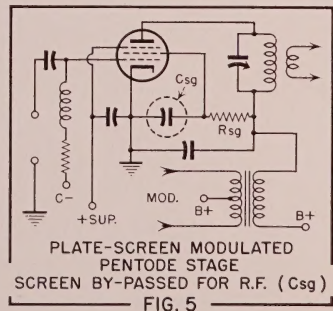
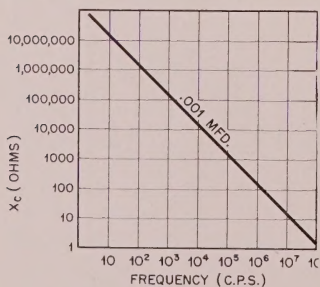


ents of both tubes flowing in the resistor are out of phase and cancel out.

Screen By-Passing

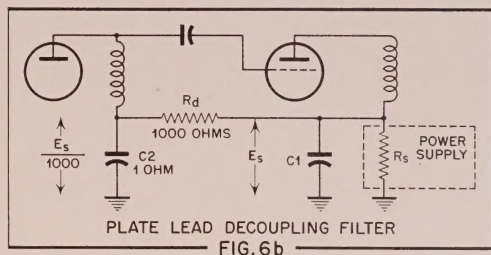
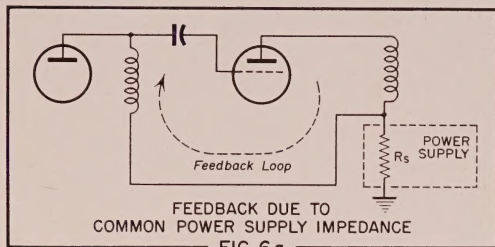
The screen element of tetrode and pentode electron tubes must be effectively by-passed to ground for all signal voltages present. This is necessary to prevent degeneration of a type very similar to that discussed above. For example, consider the television i.f. amplifier stage shown in Fig. 4. Here the screen voltage is derived from the plate supply through a dropping resistor. If the a.c. signal component is allowed to pass through the screen dropping resistor, the gain of the stage will be reduced. For this reason, a by-pass condenser is used to ground the screen for signal voltage without interfering with the application of the d.c. screen voltage. If the screen by-passing is imperfect at any frequency, the response of the amplifier will fall off there or it may oscillate. It is common practice to make the screen by-pass reactance small compared with the cathode-to-screen impedance. This is obtained by dividing the screen voltage by the screen current.

Mica or ceramic condensers are used in values ranging from 100 microfarads to .01 microfarads for radio frequencies, while high quality paper units and electrolytics are used for audio screen by-passing. As in





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cathode resistor by-passing, certain circuits require screen by-passing sufficiently heavy to ground the screen for r.f. but not for audio frequencies. A typical example of such selective by-passing would be the plate and screen modulated Class C amplifier shown in Fig. 5. In this circuit the screen voltage must vary with the modulation and so should not be by-passed for audio frequencies. A .002 microfarad condenser is sufficient in most cases and does not result in a loss of "highs".

Plate Circuit By-Passing

As in the cathode and screen circuits discussed above, any impedance in the plate circuit of a vacuum tube stage is common to another stage, or another part of the same stage, can cause feedback and instability if not properly by-passed. The reasons for this are obvious from Fig. 6a. Here the plate voltage for two stages of an i.f. amplifier are taken from the same power supply and no decoupling is employed. The internal impedance of the power supply is represented by R_s . Since the plate signal current is allowed to flow through R_s , a voltage drop is developed across it which is introduced into the plate circuit of the preceding stage via the plate lead. This signal voltage is then fed to the grid circuit of the second stage, with the result that oscillation will occur if the stage gain is high enough.

Instability due to plate circuit feedback is prevented by the use of de-

coupling filters consisting of series isolating resistors and by-pass condensers, as shown in Fig. 6b. Such decoupling networks are most easily understood if thought of as voltage dividers at the feedback signal frequency. For example, in Fig. 6b assume that the internal impedance of the power supply (R_s) is imperfectly by-passed by $C1$ at the signal frequency. A small signal voltage (E_s) is therefore developed across the power supply impedance and travels down the plate lead to the preceding stage. The function of the decoupling filter R_d and $C2$ is to greatly attenuate this signal since they divide it in the ratio of their impedances. Thus, if the reactive impedance of $C2$ is only 1 ohm and the resistance of R_d is 1000 ohms, the feedback signal is divided by that ratio so that only 1/1000th of the voltage developed across the power supply impedance is applied to the preceding stage. Of course, the d.c. plate voltage is unaffected except for a small IR drop across R_d . In cases where this drop couldn't be tolerated, an inductance could be used in place of R_d . Several such RC or LC decoupling filters are sometimes used in series in cases where feedback is particularly troublesome.

By-Passing Precautions

By-Pass wiring in some circuitry, including high gain amplifiers and VHF circuits, must be done with extreme care to avoid common impedances which introduce feedback. The

safest rule for by-passing multi-stage amplifiers is to ground all by-passes associated with the output of one stage and the input of the next stage to a single ground point, as in Fig. 7.

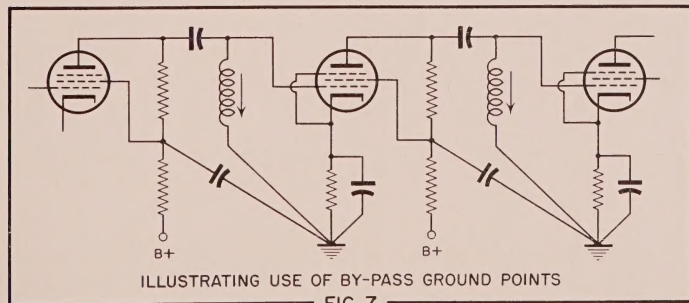
In applications where very effective by-passing at a single frequency is required, some designers have resorted to the use of *series resonant by-passing*. By this method, the capacitance of the condenser is resonated with the inductance of its wire leads to obtain the theoretically zero impedance of a series resonant LC circuit.

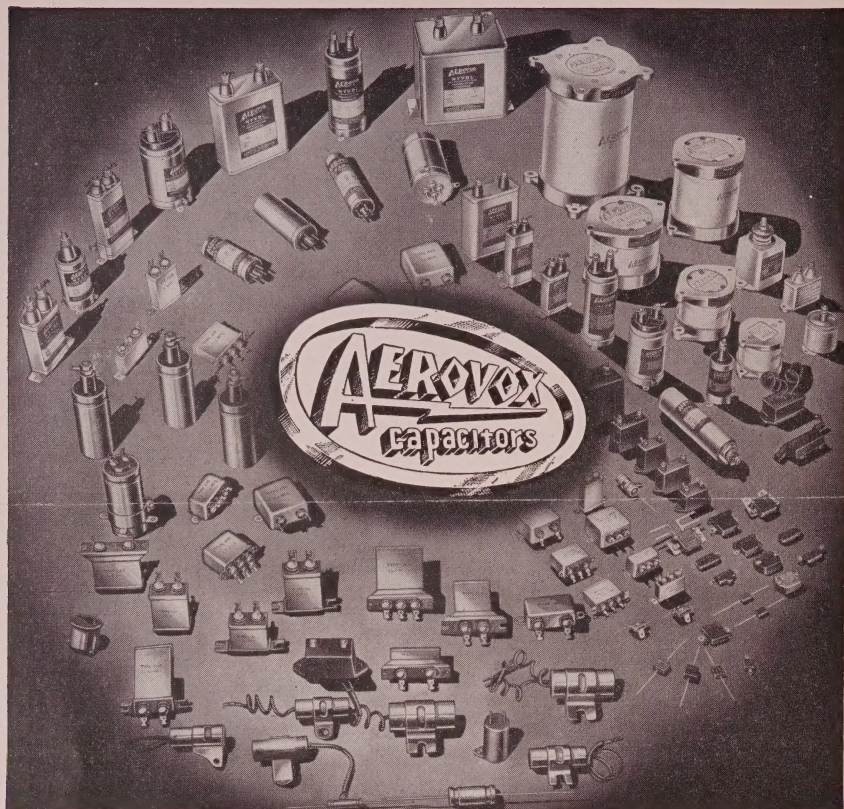
The self inductance of certain types of windings can be used and capacitors made which will have self resonant characteristics at any frequency. Such capacitors have been used in I.F. by-pass circuits of AM receivers to trap I.F. voltages.

The self-resonance of the capacitor may be found by connecting the ends of the leads together and measuring the frequency at which this L-C combination produces a response on a grid-dip meter or other absorption indicating device. The exact length of the wire lead to be used in the circuit must be used in this measurement for precise results. This is illustrated by the fact that the resonant frequency of a tubular .01-mfd unit having leads of #20 wire 1/2-inch long is about 11 mc. However, if the leads are trimmed to 1/8-inch, the self-resonance is raised to about 40 mc.

For capacitor types which do not have flexible lead wires, the terminals may be connected by a wire of known or calculated inductance and then correcting for this added inductance to find the true resonance.

Dual by-passing is frequently used where effective by-passing must be provided over a wide band of frequencies. A small, low inductance unit for r.f. is connected in parallel with a large condenser of poorer quality for audio frequencies. The high capacitance unit, if used alone, would contain too much residual inductance to be effective for r.f. and economy prevents the use of a mica or other high quality condenser of sufficient capacity to by-pass all frequencies.





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